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SUMMARY OF FY 97 WORK ON MULTIPORE SUCTION TECHNIQUES

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FOREWORD

A study was conducted at the Coastal Systems Station, Panama City, Florida on multipore suction techniques. Multipore suction techniques complement adhesive attachment research by trying to synthesize the abalone system, creating a nonadhesive alternative for attaching equipment to surfaces underwater. Several candidate geometries were developed in the early stages of this task and several geometrical parameters were identified. Two directions were pursued in these initial concepts: individual suction element, and a dense array of elements. In both cases the fundamental elements of the design involved a soft sealing surface, a cavity of variable volume, and a hard structure to provide reaction force as the cavity is distended. Prototypes of structures were designed and molds for the urethane were created by a stereolithography process.

This summary has been reviewed by R. A. Ramey, Head, Diving Systems Development Branch.

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BACKGROUND

Non-adhesive attachment systems are used by abalone, octopus, and other gastropods (shellfish) to attach and move securely over surfaces of virtually any condition or roughness using dozens or hundreds of small suction cups. This effort complements adhesive attachment research by trying to synthesize the abalone system, creating a nonadhesive alternative for attaching equipment to surfaces underwater. The proposed embodiment uses a urethane composite material basically formed as a honeycomb with flexible yet somewhat stiff walls with each pore filled with an extremely soft material (see Figure 1). Embedded in the soft core of each honeycomb would be a strand of *muscle wire* (titanium nickel (Ti-Ni) alloy) that would pull a small vacuum under electrical stimulation. A further improvement that was proposed, should the basic idea prove useful, would be to develop a *smart* system which would use a strain sensor embedded in each pore to detect vacuum. The system would control the suction of each pore by using a release/retry pump loop for those cells not holding a vacuum.

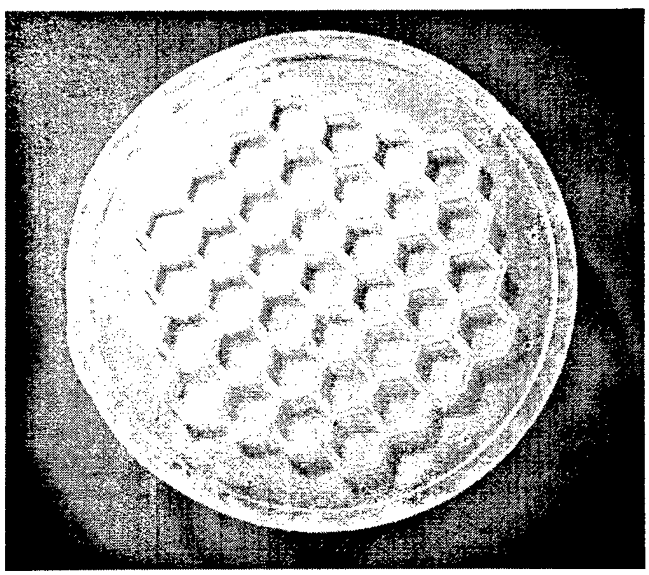

FIGURE 1. DENSELY PACKED SUCTION CELLS ARRANGED IN A HONEYCOMB STRUCTURE

FY 1997 PROGRESS

Several candidate geometries were developed in the early stages of this task, and significant geometrical parameters were identified. Two directions were pursued in these initial concepts: individual suction elements (mimicking suction cups on the arms of an octopus), and a dense array of elements (mimicking the foot of an abalone or limpet). In both cases, the fundamental elements of the design involved a soft sealing surface, a cavity of variable volume, and a hard structure to provide reaction force as the cavity is distended. Prototypes of both structures were designed, and molds for the urethane were created by the stereolithography process directly from solid model drawings.

Studying the basic process parameters proceeded along several fundamental lines including the geometry of each suction cell, the relationship between repetitive cells, the material of construction, activation of the cells, and incorporation of the cells into a useful structure.

The geometry of individual cells was taken as circular for individual cells and hexagonal for closely packed cells, but it is noted that owing to the versatility of the stereolithography process, there are no significant constraints on the shape that a cell or array of cells could take. The prototype hexagonal array mold, shown in Figure 2, would be a tedious task on a conventional milling machine since the cell wall cavities are slightly tapered to facilitate release, and the cutter path is intricate. The second mold geometry for parts resembling a conventional suction cup was more complicated, yet, with double curvatures on both concave and convex surfaces. This mold, shown in Figure 3, was produced by stereolithography working directly from a solid model computer file.

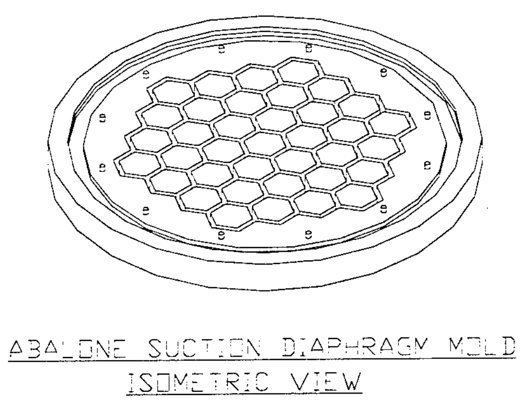

FIGURE 2. STEREOLITHOGRAPHIC MOLD DESIGN FOR CASTING THE HONEYCOMB STRUCTURE IN URETHANE

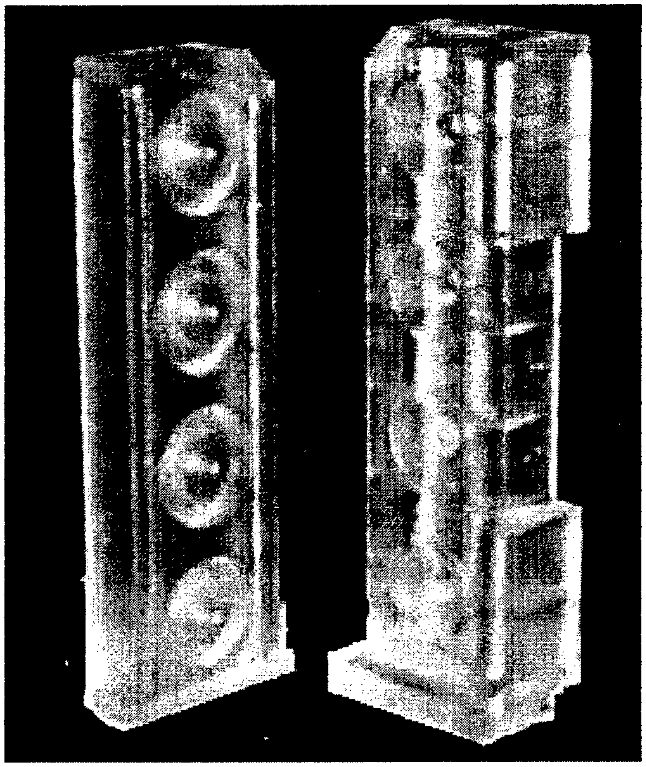

FIGURE 3. STEREOLITHOGRAPHICALLY PRODUCED MOLD
FOR INDIVIDUAL SUCTION CELLS

The densely packed array of cells, structured as a honeycomb with shared cell walls was cast in urethane to assess its potential for maximizing the working area for a given overall area. The first working model of this configuration demonstrated the effect that wall sharing can have; it is not possible to change the shape of one cell without affecting its neighbors. This turned out to be a critical factor for accommodating curved surfaces, and for conforming to roughness. The dimensional changes required for creating a suction in one cell resulted in a poor cell geometry in adjacent cells. Reducing the cell interior dimensions and thickening the walls would overcome this in some measure but would still present problems in accommodating large-scale curvature. An alternative is to slightly separate cells to allow independent orientations and cell wall deformations; for purposes of analysis across a continuum of material properties, this is equivalent to shared cell walls with composite properties, the separation between cells being considered an extremely compliant material.

Individual cells packed into an array without sharing cell walls overcomes the problems caused by interactions between adjacent cells but is less amenable to fabrication as an integrated structure than designs with shared cell walls. Nonetheless, study of the basic design parameters is facilitated by this approach. The individual cell design and two-part mold are shown in Figures 3 and 4. Actuation of the individual cells is facilitated by a hard cell case, which provides the strong back for tension on the soft cell center.

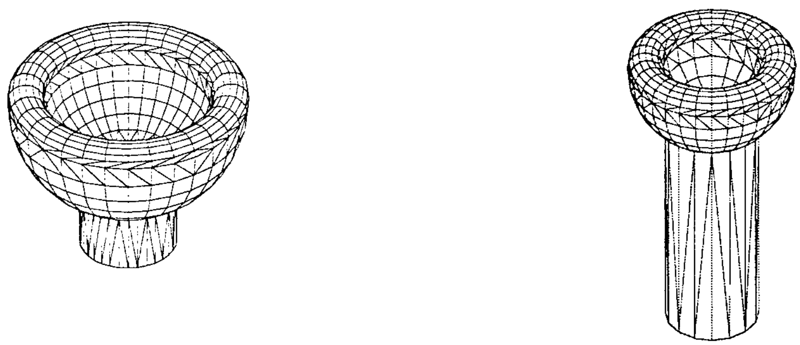

FIGURE 4. WIRE-FRAME DESIGNS FOR INDIVIDUAL SUCTION CELLS WITH DIFFERING THICKNESS TO DIAMETER RATIOS

MATERIAL OF CONSTRUCTION

A range of soft urethane and silicon materials were considered for cell construction with urethane showing far superior tear resistance and adequate adhesion to supporting structures. The urethane material is castable in the molds produced by stereolithography and releases easily. Additionally, owing to the good adhesion between new and cured urethane composite structures can be created by a sequential process. In Figure 3, the *stem* of each cell is a hard urethane, and facilitates attachment of the actuation mechanism, whereas the cup of each cell is soft (Shore A15 hardness) and serves as the deformable sealing material capable of accommodating significant roughness. In repeated trials of a large scale cell with a piston actuation sealing the soft urethane material on a corroded surface with peak-to-peak roughness in excess of 0.1 in. was possible regardless of the exact location on the corroded specimen.

ACTIVATION

Activation of the multipore suction device requires tension to be applied to the center of each cell while the perimeter is held in contact with the surface. In conventional suction cups, the tensile force is supplied by precompression of the cup itself, or by evacuating the air under the cup, and the volume captured between the cup and the sealing surface changes in response to the decreased air pressure under the cup. Both of these mechanisms are applicable underwater as well although the compressibility of water (and hence the change in captured volume) is negligible. The incompressibility of water is an asset in activating the multipore suction device, since virtually no physical volume change is necessary to create a low pressure region between the suction cell and the sealing surface. For this reason, *muscle wire*, composed of a Ti-Ni alloy, was proposed as a means of activating the device.

Ti-Ni alloys can exhibit significant dimensional changes as they pass from the alpha to martensite phase, a change that can be induced by heating or cooling the material. This property has been exploited in *muscle wire* but has not yet been incorporated into the multipore suction device.

Alternative means of tensioning the suction cells include the previously mentioned compliance of the urethane itself and variations based on composite structures formed of urethanes or other materials with appropriate stiffness values as well as evacuating water in the individual cells by means of a diver actuated pump. Note that the actual change in volume is only the amount that results from compressing the soft urethane seal, since the water is essentially incompressible.

STRUCTURES

The major issues in creating a structure that incorporates a large number of suction cells are application of external forces; large-scale compliance to accommodate curvature; and distribution of the activation signal (electrical, mechanical, or hydraulic) to each individual element. At the present time, it is thought that binding individual suction cells in a very soft matrix will allow the proper local orientation of individual cells. That matrix would, in turn, be bound to a hard, external shell to distribute external forces.

Figure 5 shows the concept of an integrated multipore suction device able to accommodate both large scale curvature and small scale roughness. In this design, each suction element is activated individually, and has a hard cell wall to provide reaction forces. The ensemble of elements is embedded in a compliant matrix through which the total adhesive force is transmitted to the hard shell to which useful attachments can be made.

CONCLUSIONS

In FY 97 several concepts for a multipore attachment device were investigated, and molds for prototype devices were fabricated using the stereolithographic rapid prototyping process. One concept, with cells sharing common walls in a honeycomb configuration, was tested with limited success. This device served to clarify interactions between adjacent cells, each requiring some geometric distortion to produce a vacuum, and prompted a second design in which individual cells are isolated by hard cell walls, and embedded in a compliant manner. This latter configuration more closely matches the discrete suction cups used by certain cephalopods, notably the octopus. A continuation of FY 1997 work in FY 1998 is expected to produce a functional prototype.

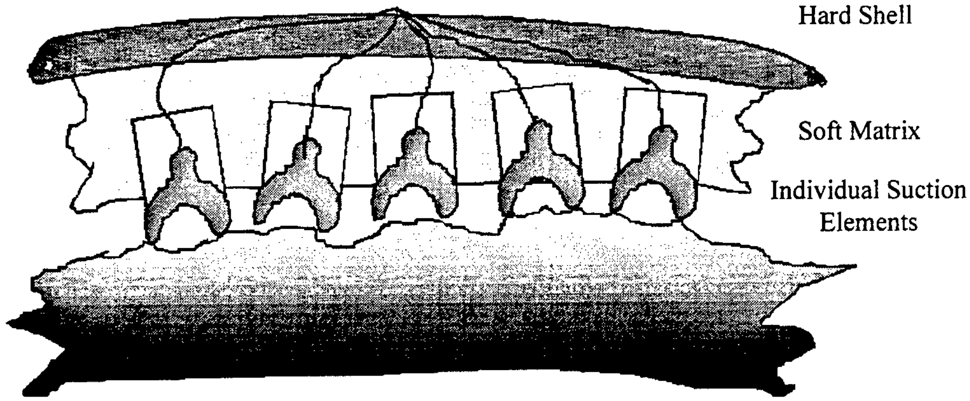

FIGURE 5. STRUCTURAL CONCEPT

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